5.0 ENGINE LUBRICATION SYSTEM

This chapter presents the major components of the engine lubrication system and explains how the system is necessary for the reliable operation of the engine.

Learning Objectives

As a result of this lesson, you will be able to:

1. Define lubrication and the types of friction.
2. State the function of the diesel engine lubrication system.
3. Identify the major components of the typical diesel engine lubrication system and trace the flow path of the lubricating oil through the engine.
4. State the purpose and describe the operation of the lubrication oil keep warm and pre-lube system(s) as are commonly used on nuclear application diesel engines.

5.1 Lubrication Fundamentals

Diesel engine operation involves the movement of assorted shafts, gears, cams, pistons and levers to transmit forces and loads between components within the engine. As with all types of mechanical equipment, where there is relative motion and forces, there is friction.

5.1.1 Friction

Friction: *The force that acts at the surface of contact between two bodies which causes resistance to their relative motion.*

5.1.1.1 Frictional Surfaces - There is no such thing as a "perfectly" flat or smooth surface. If we take a microscopic look at two surfaces in contact, as in Figure 5-1, each surface consists of a series of peaks and valleys. As one surface attempts to move relative to the other, the peaks contact one another creating a resistance to the movement.

When the force of movement is great enough, the peaks are forced over each other wearing away the two surfaces. Along with the wearing action is the generation of heat. Types of friction are illustrated in Figure 5-2.

5.1.1.2 Sliding Friction - Sliding friction occurs where relative motion exists between two parallel surfaces. Sliding friction presents the greatest resistance to motion along with the greatest wear and heat generation.

5.1.1.3 Rolling Friction - In an attempt to reduce friction, it was discovered that by placing a spherical or cylindrical rolling element between two surfaces, friction was substantially reduced. From this concept of rolling friction came the development of ball and roller type bearings.

It would appear that rolling friction would present almost a zero resistance to motion, wear, and heat generation because no sliding motion is present. Such is not the case. If we look closely at a rolling element as shown in Figure 5-3, we can see how the element and the surface it contacts deform slightly when the load is applied.

This changes the configuration from one of pure rolling contact to a combination of rolling and sliding. Since sliding does occur, there is wear and heat generation. Though less than would occur with sliding friction, some friction is still present.

5.1.1.4 Fluid Friction - The third type of friction we will encounter is that which occurs when a solid body moves against a fluid. As the body moves, the fluid shears in layers as it moves away from the body. Fluid friction offers the least resistance to motion with a minimum of wear and heat generation.

5.1.2 Lubrication

Lubrication is the process whereby sliding friction and rolling friction are converted to fluid friction by placing a viscous film between the two surfaces. With a film of sufficient thickness, the two surfaces are separated and no contact occurs.

5.1.2.1 Laminar Action - As shown in Figure 5-4, when the two surfaces are separated by the fluid film and relative motion occurs, the lubricant separates or shears in layers. With this laminar action, fluid friction is the result of the fluid layers moving against each other and not the two surfaces.

5.1.2.2 Wedge Formation - When lubrication is applied between two surfaces which are not parallel and relative motion occurs, a wedge of lubrication is formed. As shown in Figure 5-5, the layers of lubrication are forced through a narrowing space between the two surfaces. This creates an upward force which supports the loads imposed on the shaft while keeping the two surfaces separated.

5.1.2.3 Shaft and Bearing - The situation shown in Figure 5-6 is typical of a crankshaft and bearing. The diameter of the shaft is slightly smaller than the bore of the bearing. This creates an oil clearance and non-parallel surfaces as before. Oil is supplied to the bearing through the hole in the top.

With the shaft stationary, it rests in the bearing as shown. There is metal-to-metal contact but with no motion, no wear, nor heat build-up.

Initial rotation of the shaft causes it to climb the bearing as shown in middle diagram of Figure 5-6. As the climbing action begins, the oil is pushed into the space between the shaft and bearing due to the oil’s ability to adhere to both surfaces. The action of the oil separates the two components creating a film of lubrication.

As the shaft comes up to operational speed, a high pressure wedge is formed, supporting the shaft while preventing metal-to-metal contact. This high pressure area is referred to as a hydrodynamic oil film.

5.1.3 Lubricants

The fluid used to create the separation of the internal components of the emergency diesel generators is most frequently a lubricating oil specifically formulated to provide long engine life and maximum reliability.

5.1.3.1 Lubricant Functions - In order to ensure reliable operation, diesel engine lubricants must perform four functions.

- Provide a film of lubricant between the moving parts of the engine to prevent metal-to-metal contact.

- Create an oil film between the piston rings and cylinder wall to ensure a gas tight seal.

- Remove and dissipate heat developed by the engine internals.

- Help keep the internal surfaces of the engine clean.

5.1.3.2 Properties of Lubricants - For a lubricant to perform the functions listed above, it must possess certain properties.

- **Viscosity** - The ability of a lubricant (such as oil) to maintain a fluid film between two surfaces when acted upon by load or force. Viscosity is a measure of the oil's resistance to flow. The thicker the oil, the higher its viscosity.

- **Viscosity Index** - The viscosity of an oil is affected by temperature. As the oil temperature increases, the viscosity decreases. Viscosity index (VI) is a measure of the ability of the oil to resist the effects of temperature. An oil with a high viscosity index is less subject to change due to temperature than an oil with a low VI. However, it is recommended that multi-viscosity lubricants not be used in these heavy duty engines.

- **Pour Point** - Refers to the temperature at which the oil is considered to be too thick to flow. Since nuclear class diesels are housed in a controlled environment and in most cases provided with supplemental heat, pour point is a minor concern.

- **Oxidation Resistance** - When oil is subjected to extremely high temperatures such as those of the pistons, rings and cylinder walls, the hydrocarbons in the oil combine with the oxygen in the air to produce highly corrosive acids which tend to form gum or lacquer type deposits on the engine's internal components.

  If allowed to build up, these deposits can cause corrosive damage to engine parts and lead to sticking of piston rings and valves. To combat the problems of oxidation, specific chemicals are added to the engine oil which reduces the tendency of the hydrocarbons to combine with oxygen.

  The terms usually associated with oxidation resistance is the TBN and TBA numbers. These are obtained when an oil is analyzed. An oil in good condition has a high TBN (Total Base Number). As oxidation builds up the TBN goes down and the TAN (Total Acid Number) goes up. The oil should be changed when the TAN becomes larger than the TBN.

Some units require lubricating oils with certain properties, such as the EMD engines with silver conrod/wrist pin bushings. The manufacturer's recommend oil should only be used in such units.

For highly turbocharged engines, naphthene base stock lubricants as opposed to paraffin based lubricants are sometimes recommended. While paraffinic lubricants tend to be better at lubrication, the paraffin tends to form more deposits within the engine and turbocharger.

5.2 Lubrication Systems

The function of the lubrication system in a diesel engine is twofold.

- First, it reduces wear and heat generation by placing a film of lubricating oil between the parts of the engine.

- Second, it removes a portion of the heat generated as a normal part of engine operation. This heat is then transferred out of the lubricating oil system through the lube oil heat exchanger.

Regardless of the engine type, the lubrication system must provide an adequate supply of clean, cool lubricating oil to all key engine components. A typical engine lubrication system is shown in Figure 5-7.

5.2.1 Lube Oil Sump

The lube oil sump stores a sufficient quantity (e.g. 800 gallons) of lubricating oil to meet the operating needs of the engine. It provides a place where any solids and water in the system can separate out while letting any entrapped air vent off. Depending on the specific design of engine, there are two types of lube oil sumps which may be encountered.

5.2.1.1 Wet Sump - In the wet sump system, the lube oil sump is the integral part of the engine directly below the crankshaft. The sump in this case is referred to as an oil pan or crankcase and is attached to the engine base or block assembly. Oil, having passed through the engine, returns to the sump by gravity.

5.2.1.2 Dry Sump - With a dry sump, the oil is stored in one or two separate tanks located a short distance from the engine. Oil, which has passed through the engine, drains back to the engine base and returns to the remote oil sump by gravity.

5.2.2 Lube Oil Pump (Figure 5-8)

The lube oil pump is usually a positive displacement gear pump mounted on and driven by the engine accessory drive. It draws suction from the sump and supplies the oil through a set of strainers and/or filters to the engine main lube oil header.

Rotation of the gears as shown creates a partial vacuum at the suction side of the pump. This vacuum draws oil from the lube oil sump into the pump where the oil is trapped by the gears. Oil is carried around the pump housing to the discharge side. As the gears mesh, the oil is forced out of the housing creating flow needed for engine lubrication. Pressure is created simply because there is downstream resistance to the flow.

5.2.3 Lube Oil Strainers

Most of the larger engines are equipped with lube oil strainers. These are similar to lube oil filters except that they are intended to filter (strain) out larger particles that could damage engine parts, particularly main bearings and other close clearance parts. The strainer is usually rated to take out particles larger than 20 to 50 micron in size. All of the oil going to the engine passes through the strainer.

Oil from the lube oil pump enters the strainer housing, either before or after the oil has been cooled. Some units have two strainer units and valving such that the strainer elements can be removed for cleaning while the engine is in operation. Like the fuel oil filters, it equipped with a valving system. The valve should be set up to use only one strainer element at a time, thus reserving the other unit for immediate use should there be a problem. The system should never be able to bypass the strainer elements.

5.2.4 Lube Oil Filters (Figure 5-9)

Lube oil filters, typically rated at 5-10 microns, clean the oil by removing any solid particulates and fluid contaminants which develop during engine operation. These filters usually consist of replaceable elements with a paper or fibrous type media.

Very often the lube oil filter does not filter all of the engine oil and may also be run along with the keep warm system during periods when the engine is not running. The filter is intended to take out the very fine particle such as the ‘soot load’ that accumulates in the oil sump. These particles will pass through the engine without doing damage, but it is desirable to remove them as they contribute to the buildup of acids and lacquers in the lube oil system.

The lube oil filter may also be ‘duplexed’ with valving to allow the filter’s elements to be changed out while the unit is in operation. Many filter elements are throw-away types, while others may be cleaned or refurbished.

5.2.5 Lube Oil Cooler (Figure 5-10)

As the oil travels through the engine, it picks up heat from various engine components such as pistons, piston rings, bearings, cams, and valve operating mechanism. If this heat is allowed to build up, the oil will eventually overheat, leading to a chemical breakdown and loss of lubricating ability.

The lubrication oil cooler removes this excess heat and transfers it to a suitable cooling medium such as the engine jacket water cooling system. The cooler is normally a shell and tube type with cooling water passing through the tubes while the oil passes over the outside of the tubes (in the shell).

5.2.6 Lube Oil Header

The lube oil header or headers along with internal and external piping deliver the lubricating oil to all the critical engine components. System ancillary piping is typically designated ANS Class 33, designed for seismic loading.

Some engines such as the Fairbanks Morse Pielstick engines have a separate lube oil system of headers to supply lubricating oil to the valve rocker assemblies located in the cylinder head covers. This separate system receives oil from the main lubrication system but has a separate tank to store the oil along with a separate pumping system. In this way, oil that might become contaminated with water or sediments, etc. is not returned to the main lube oil system.

5.2.7 Pressure Relief Valve (Figure 5-11)

Many engines use a simple spring-loaded pressure relief valve located on the lube oil pump or at the downstream end of the main oil header. This type valve limits oil pressure by opening when the pressure exceeds a specified value.

Lube oil pressure from the main oil header or pump is applied to the bottom of the valve as shown in Figure 5-11. The maximum lube oil pressure is set by adjusting the pre-load of the spring which acts to hold the valve closed. When the lube oil pressure exceeds the force of the spring, the valve lifts and the excess pressure is returned to the lube oil sump.

The opening pressure and rated flow for the valve is determined by the engine manufacturer to protect the engine lubricating oil system from over-pressurization, particularly during cold starts when the oil temperature is low and the viscosity is high.

5.2.8 Pressure Regulating Valve (Figure 5-12)

Some larger engines may use a spool type pressure regulating valve at the inlet to the main oil header. This type valve responds to flow and pressure demands to maintain a constant and correct oil supply to the engine or engine accessories that need a restricted oil pressure.

Lube oil under pressure enters through the sleeve near the center of the spool valve. This pressure is also directed to the sensing chamber where it acts against the end of the spool valve. The desired lube oil pressure for the engine is set by pre-loading the spool valve spring with the adjusting screw. As the oil pressure reaches the set-point of the valve assembly, the pressure overcomes the force of the spring causing the spool valve to move to the right. As it does, the valve opens to allow excess oil pressure to bypass through the ports at either end of the sleeve and return to the oil sump.

5.2.9 Engine Pre-lube/Keep Warm-System (Figure 5-13)

During the time when an engine is shutdown or in a standby mode, most of the lubricating oil drains away from the engine components and returns to the lube oil sump. Therefore, when an engine is started, there is minimal lubrication available to protect the vital components. It takes time for the lubrication system to develop the required pressure and flow.

The lube oil prelube/keepwarm system provides a metered flow of temperature-controlled oil to selected engine components. This reduces the wear and damage which can occur during 'dry' starts. The flow of oil is metered to prevent excess oil from flooding localized areas of the engine such as cylinder heads or upper pistons on the opposed piston engine. Excess oil flow through stationary engine bearings can erode grooves or channels in the fairly soft precision bearing surfaces.

Figure 5-13 shows a basic lube oil system that includes the prelube and keepwarm system components for a typical engine.

5.2.9.2 Prelube/KeepWarm Pump - The prelube or keepwarm pump is an electrically driven, positive displacement pump which draws suction from the lube oil sump and supplies oil to the main lube oil header and other selected points.

A relief valve is provided to protect the system from over-pressurization. Metering valves are often installed at specific locations such as the turbocharger oil inlet to prevent localized flooding.

5.2.9.1 KeepWarm Heater - To further protect the engine during startup, a thermostatically con-trolled immersion type heater is placed either in the lube oil sump or in a bypass tank. This heater maintains the lubricating oil at or near its normal operating temperature.

If the keepwarm heater becomes inoperable, the diesel generator is not degraded as long as the engine lubricating oil temperature remains above the minimum acceptable temperature specified by the manufacturer for operability (e.g. greater than110^{o}F).

5.2.9.3 Prelube/KeepWarm Filters and Strainers - Strainers and filters similar to those used in the main lubrication oil systems are also installed in the prelube/keepwarm system to protect the engine components from damage by abrasive particulates.

5.2.9.4 Check Valve - The check valve is installed to prevent the flow of main lubrication oil into the prelube/keepwarm system when the engine is operating and the prelube/keepwarm system is shut down.

5.2.9.5 System Operation - The prelube/ keepwarm system is operational during the periods when the engine is in the standby mode. An engine start causes the system to be de-energized. After shutdown, the system is again energized.

Some installations separate the prelube and keepwarm functions. The keepwarm system provides the metered temperature-controlled oil at all times when the engine is in standby. The separate prelube system employs a full flow prelube pump which is manually activated for a short period prior to a manual engine start.

The Fairbanks Morse Opposed Piston engine has special requirements because of having an upper crankcase. If this engine was prelubed like other units, there is a good chance that the upper pistons could be filled with lube oil. This oil can leak down past the piston rings on the upper pistons and cause a hydraulic lock of the engine. To prevent this, the engine is prelubed by hand in case of a manual start.

In the case of an unplanned automatic start, the upper portion of the engine is not prelubed. The keepwarm system has special controls that provide sufficient pressure and flow of warm oil flow to keep the lower part of the engine pre-lubed and warmed. This system is shutdown while the engine is running and is held off by a time delay signal when the engine is shutdown to allow time for the oil to drain down from the upper crankcase area. If the keep warm oil temperature drops below a minimum, the keepwarm system is shutdown to prevent oil from getting into the upper crankcase area.

5.3 Crankcase Vacuum

The cylinders of most engines are not intentionally fed lube oil. The system relies on oil being splashed onto the lower end of the cylinders by the flailing of oil off the crankshaft and connecting rods or by the drain down from the pistons. This flailing also results in the build-up of oil vapors in the crankcase. Since there is also air in the crankcase, it can become a combustible mixture in the crankcase. Then, if a hot spot develops such as a hot bearing, this could ignite the vapor-air mixture and cause an explosion within the crankcase.

The crankcase must be strong enough to withstand such an explosion. But, it is also desirable to mitigate the possibility of such an explosion. This is generally done by venting the crankcase so that vapors will not build up to the point of becoming a significant combustible mixture. On most large engines, the crankcase is put under a slight vacuum by having a connection on the crankcase which is connected to a source of vacuum. This vacuum may be provided by an ejector system or by a motor driven blower/pump.

Also, there are combustion gases entering the crankcase from the imperfect sealing of the combustion space by the piston rings to the cylinder. As the piston rings wear over time, the volume of combustion products entering the crankcase increases. Some of the elements in these gases may be combustible.

Keeping the crankcase under a slight vacuum (0.5 to 1.5 inches of water) has two beneficial aspects:

1. Air is drawn into the crankcase through clearances such as engine end bearings and incompletely sealed gaskets such as at the crankcase cover doors. This draft of air prevents lube oil from leaking out of the crankcase at those same locations.

2. Vapors are drawn from the crankcase and exhausted to the atmosphere often through the engine exhaust piping. With air drawn into the crankcase and vapors drawn out, the mixture in the crankcase is too lean to easily ignite or for a flame to propagate in the event there is a hot spot in the crankcase.

The oil vapor that is drawn from the crankcase is generally put through a wire mesh ‘strainer’ which tends to condense some of the oil vapor droplets, and the condensed liquid is returned to the crankcase.

The crankcase pressure/vacuum is generally monitored and used as an indication of a problem in the engine power parts. For instance, failure of a piston or of piston rings usually results in an increase in blow-by of combustion gasses into the crankcase and an increase in crankcase pressure. A switch is mounted on the crankcase to monitor the crankcase pressure. A tripping of the switch then indicates a problem in the engine.

A cross-section of a typical crankcase pressure/vacuum switch is shown in Figure 5-16. The large area of the diaphragm is used to increase the force (force = Pressure times Area) acting on the switch push-rod. As the pressure goes from slightly negative to slightly positive, the diaphragm pushes the switch pushrod toward the switch assembly. This closes the switch contacts, causing a crankcase pressure alarm and perhaps initiating an engine shutdown.

The output of this switch, when operated by an increase in crankcase pressure or a decrease in crankcase vacuum, will initiate an alarm and if provided with multiple sensing, a shutdown of the unit.

Some units have also been provided with temperature monitoring of the engine main bearings. A typical main bearing temperature monitoring thermocouple or resistance-temperature-detector (RTD) is shown in Figure 5-17. It should be noted that the temperature sensor does not touch the crankshaft but only monitors the temperature of the back of the bearing. If the bearing is in the process of failing, that temperature will increase rapidly enough to alert the operator to the problem in time to possibly prevent a total failure of the bearing or the crankshaft surfaces.

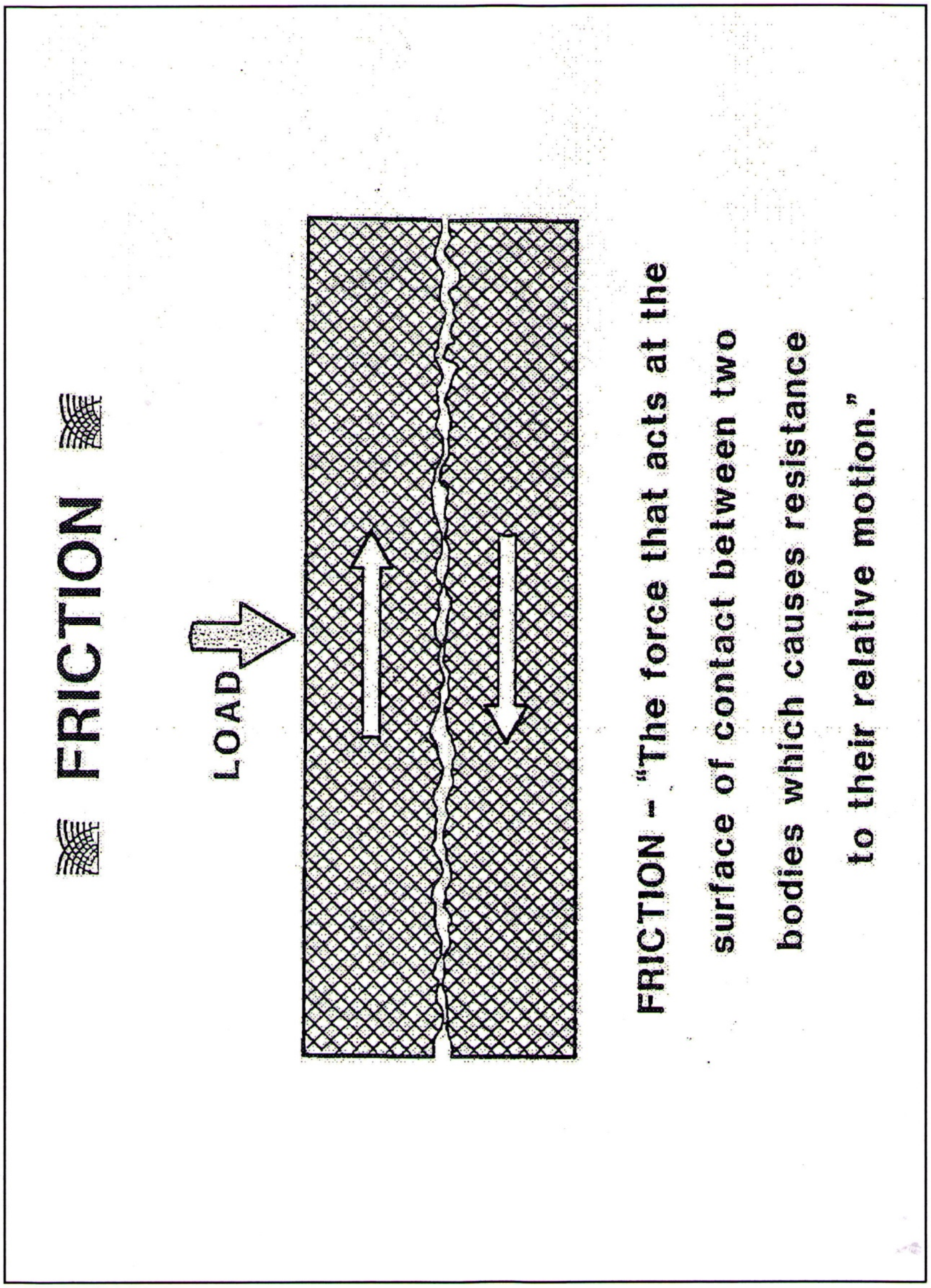

Figure 5-1 Frictional Surfaces

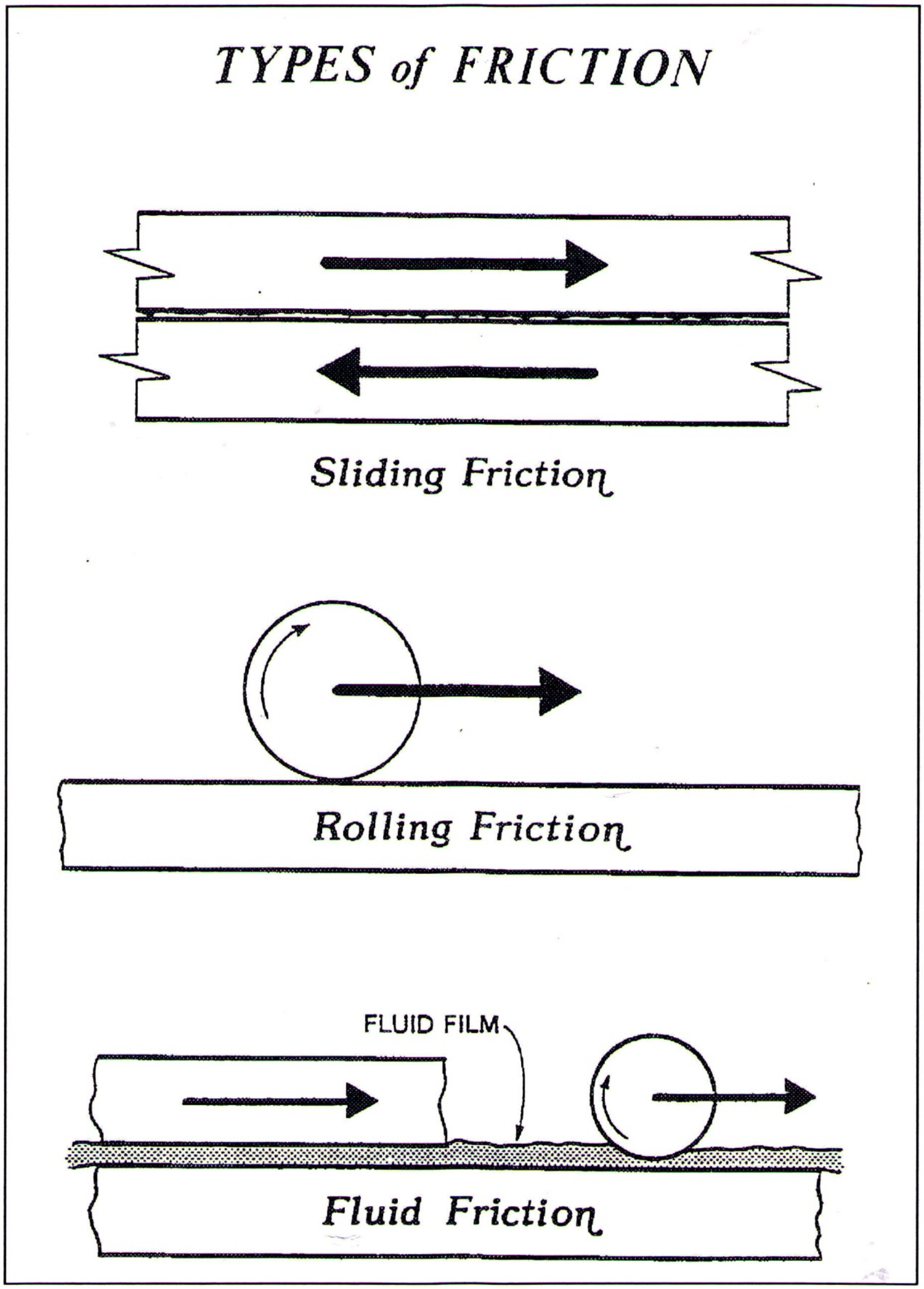

Figure 5-2 Types of Friction

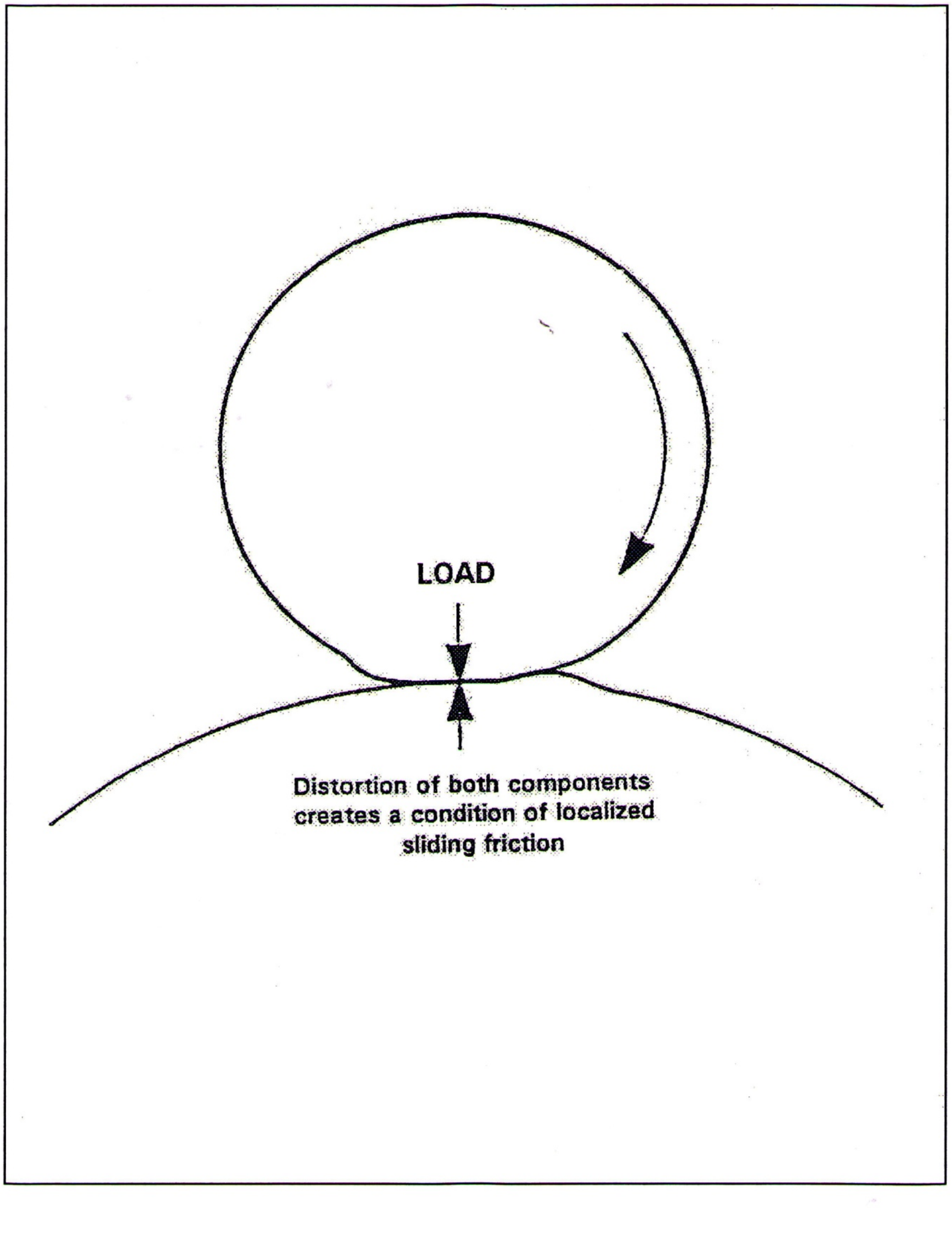

Figure 5-3 Rolling Friction

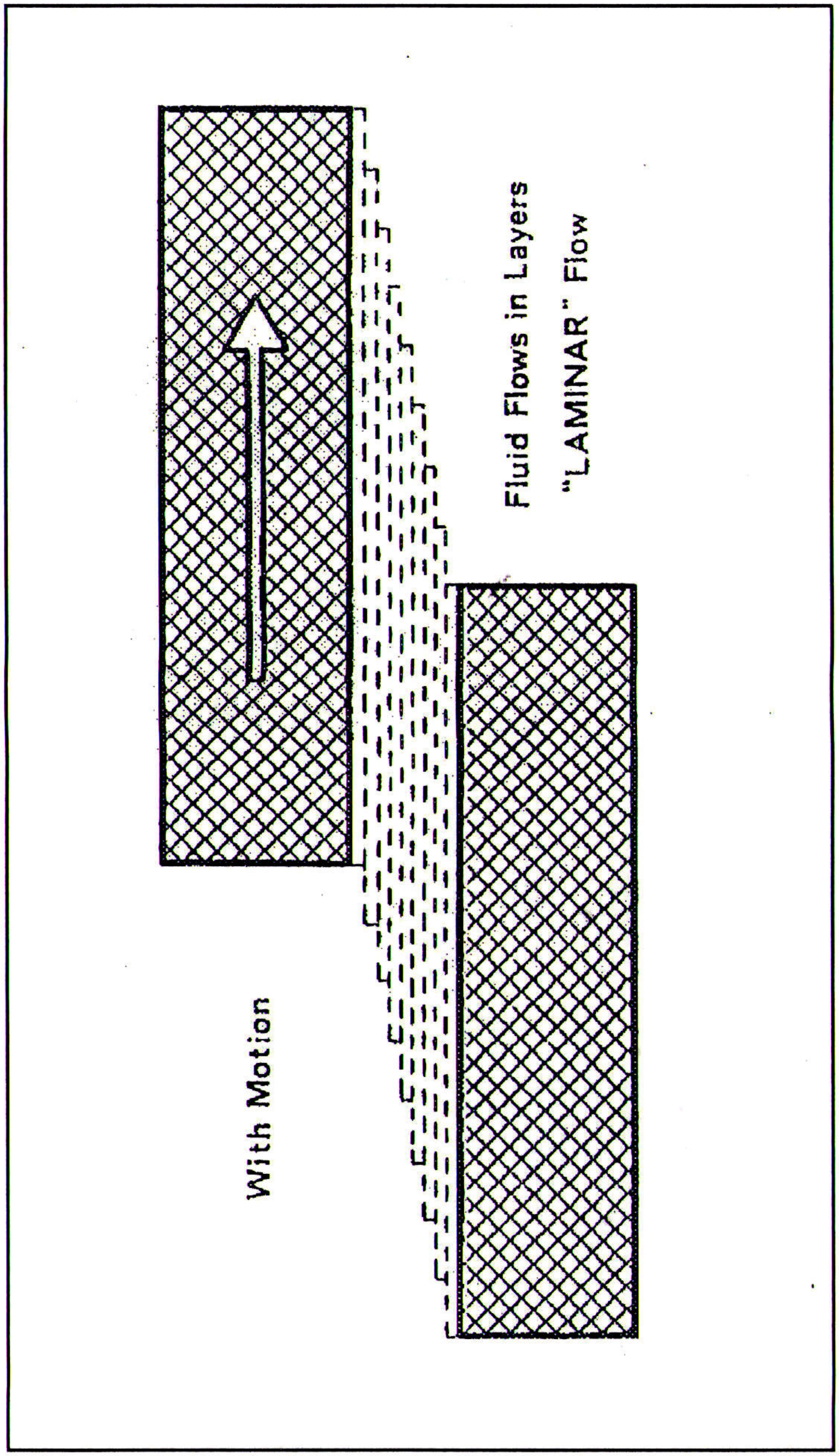

Figure 5-4 Laminar Action

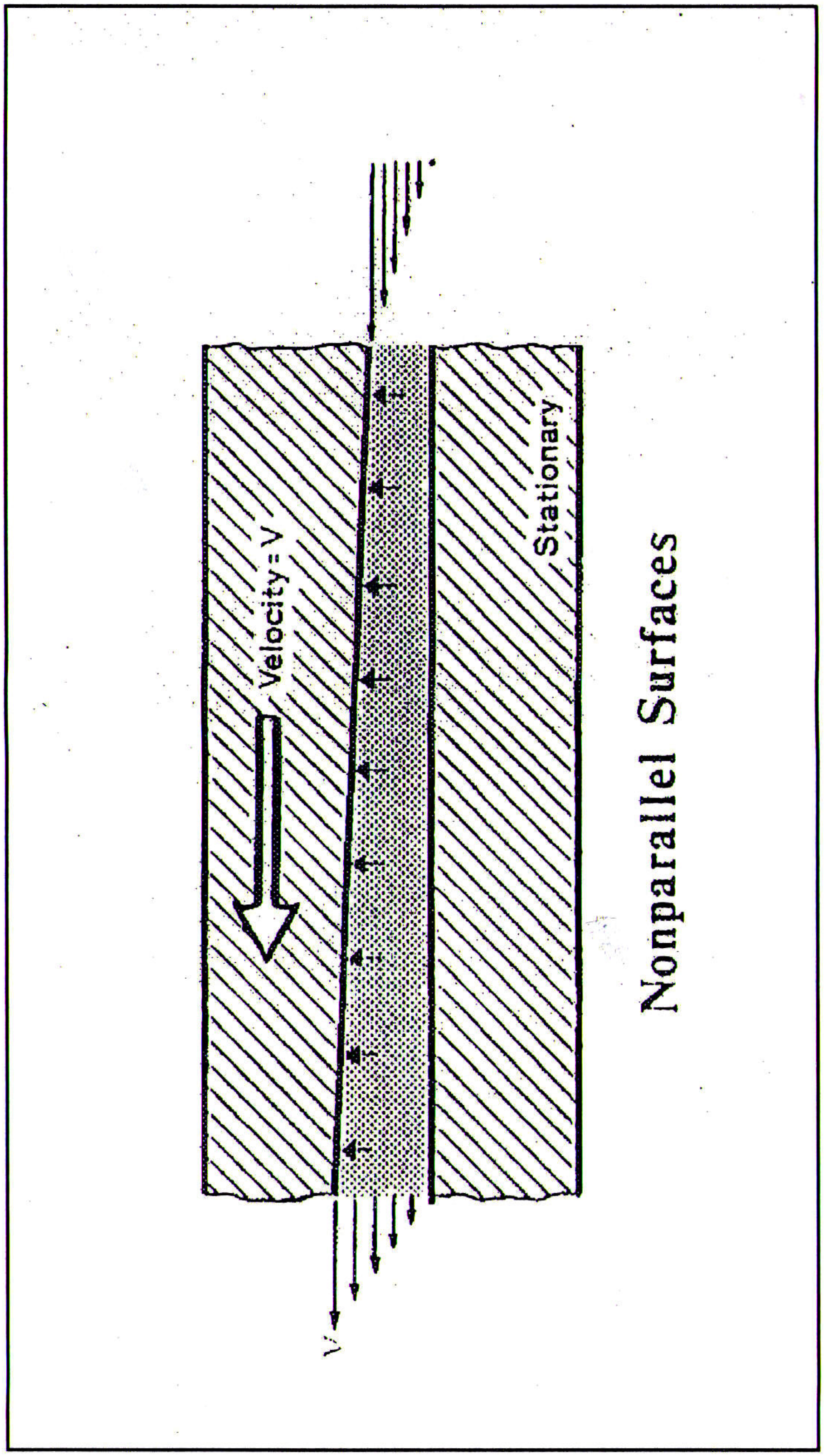

Figure 5-5 Wedge Formation

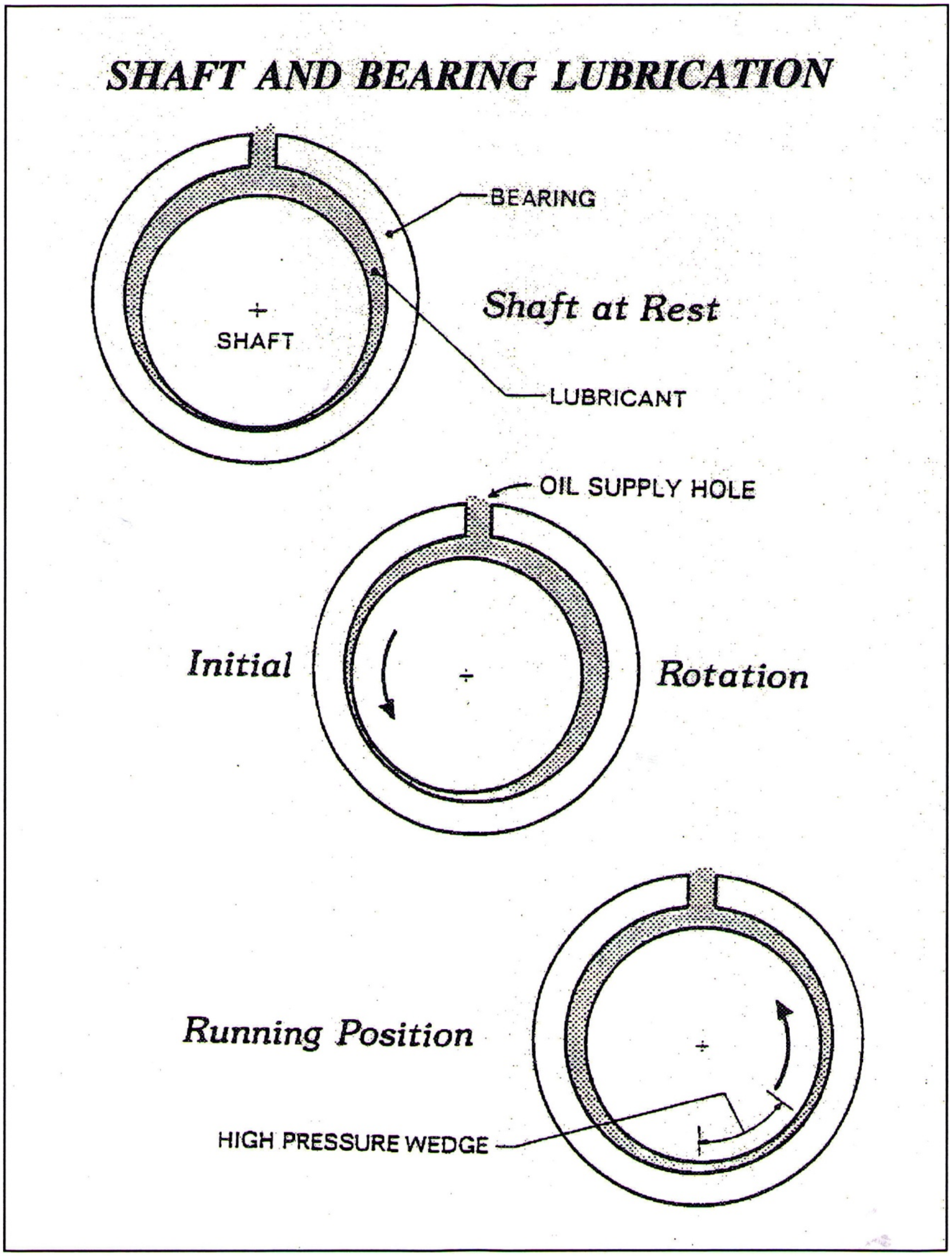

Figure 5-6 Shaft and Bearing

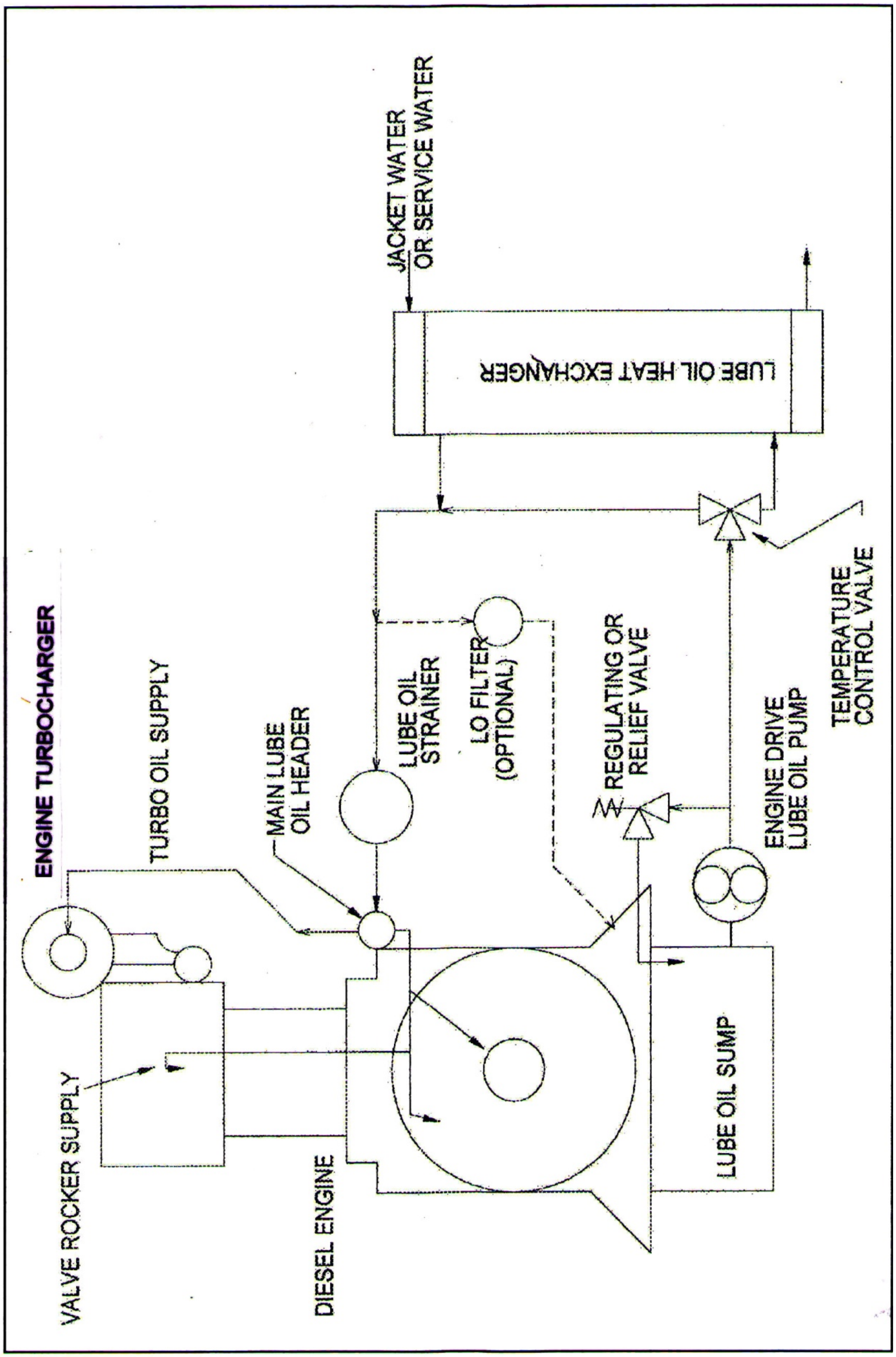

Figure 5-7 Lube Oil Circulating and Cooling System

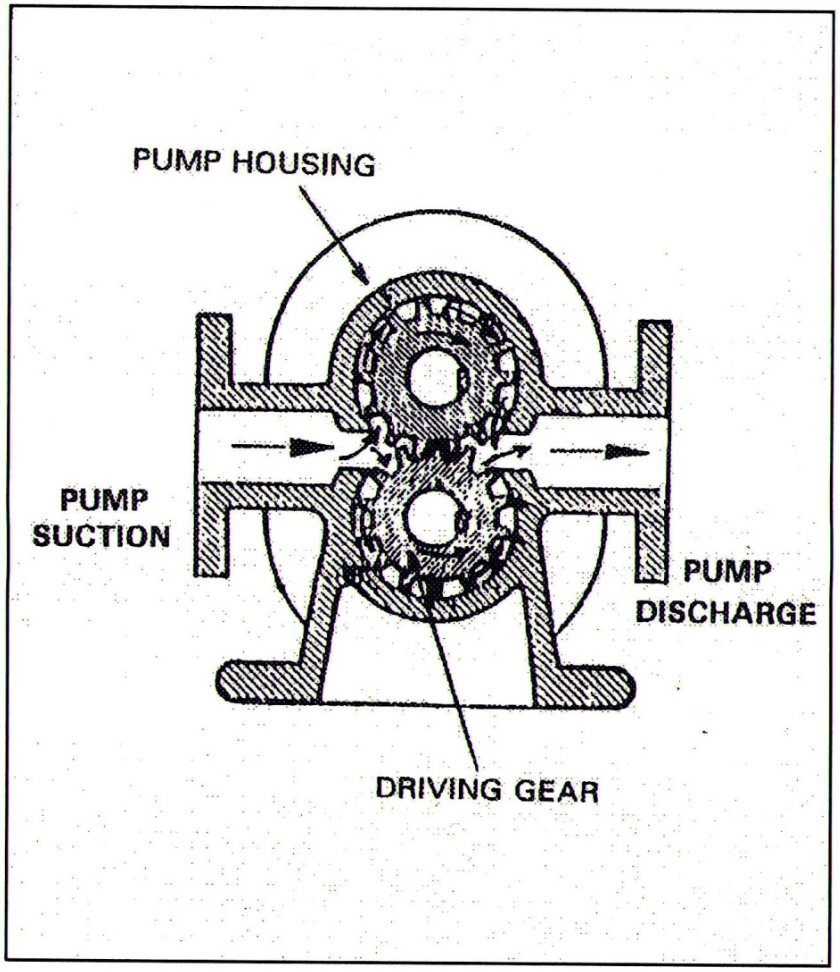

Figure 5-8 Lubricating Oil Pump

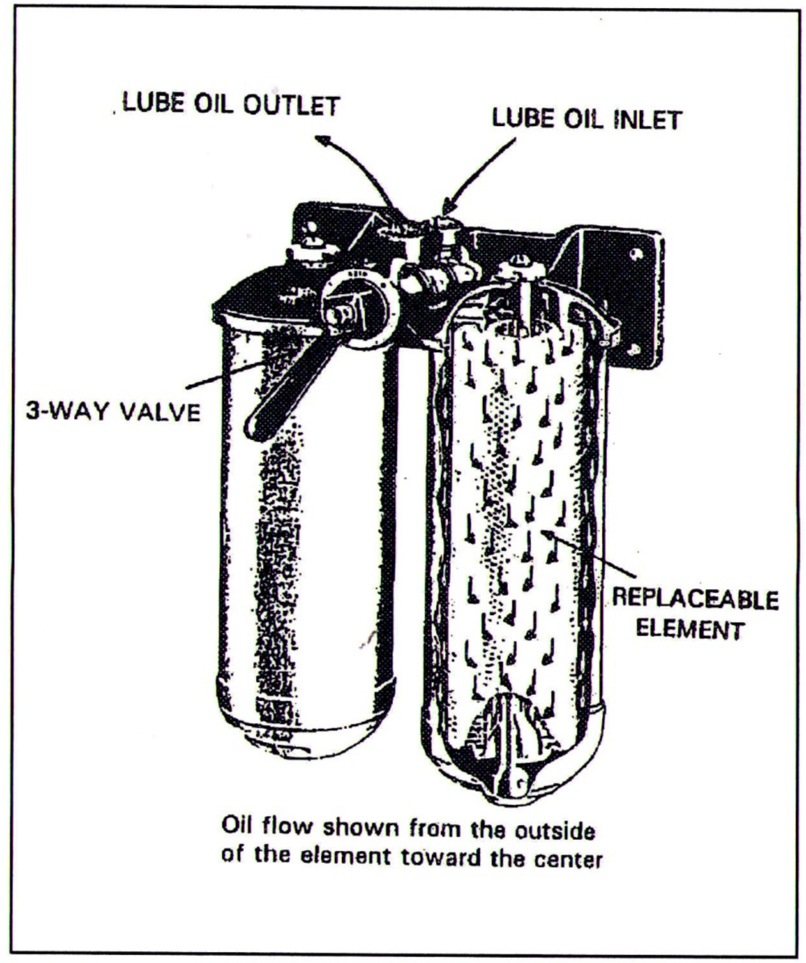

Figure 5-9 Lubricating Oil Filters

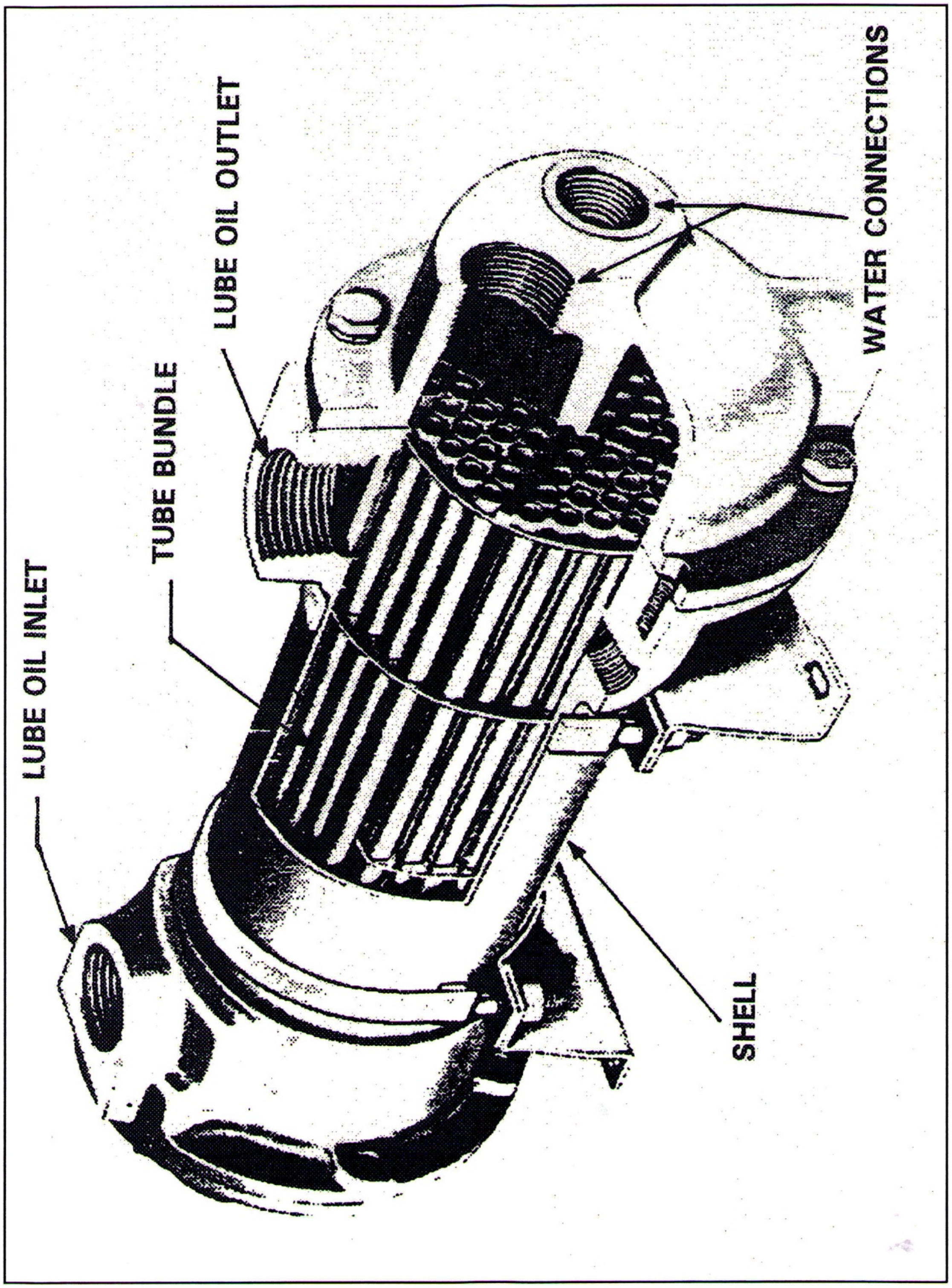

Figure 5-10 Lubricating Oil Cooler

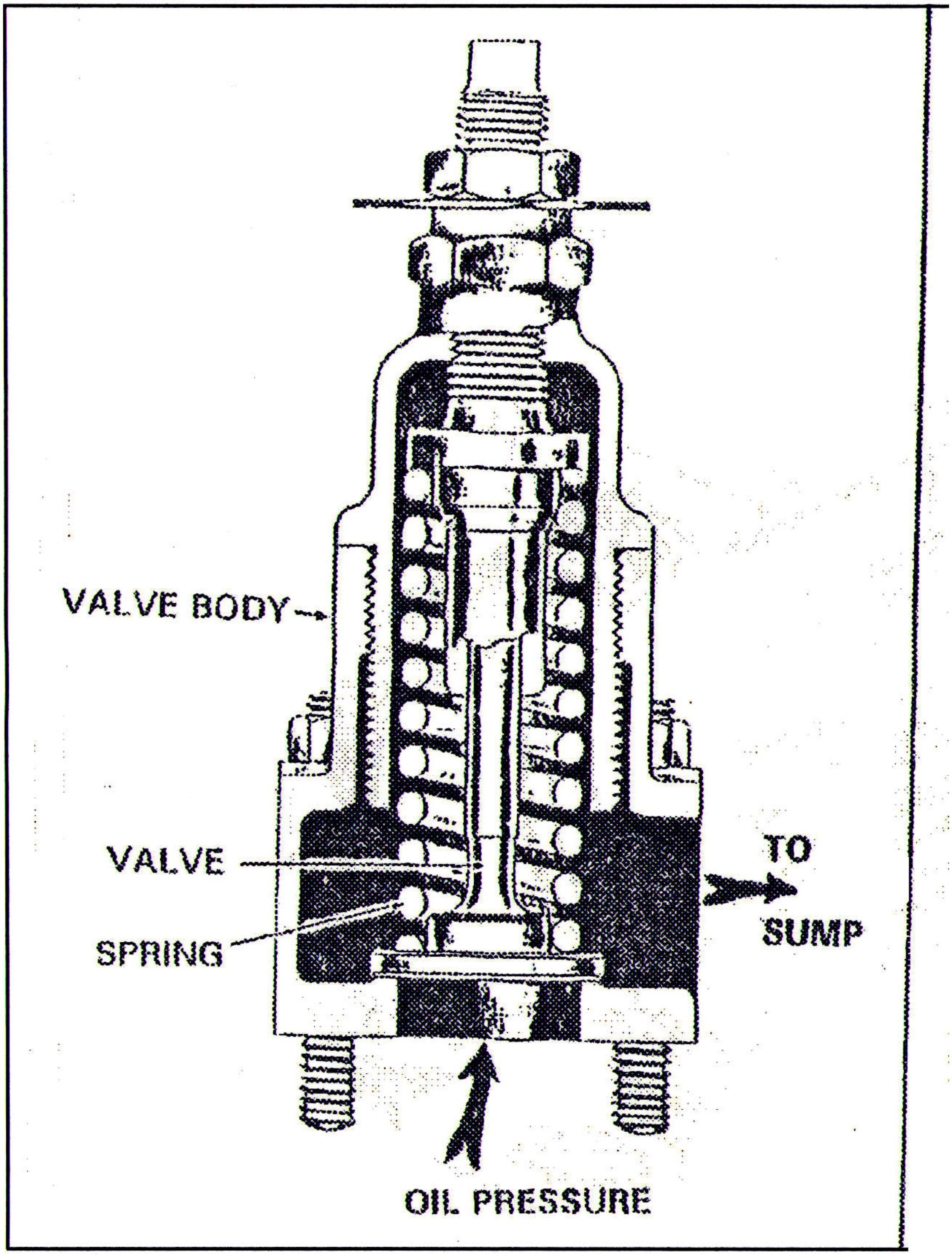

Figure 5-11 Pressure Relief Valve

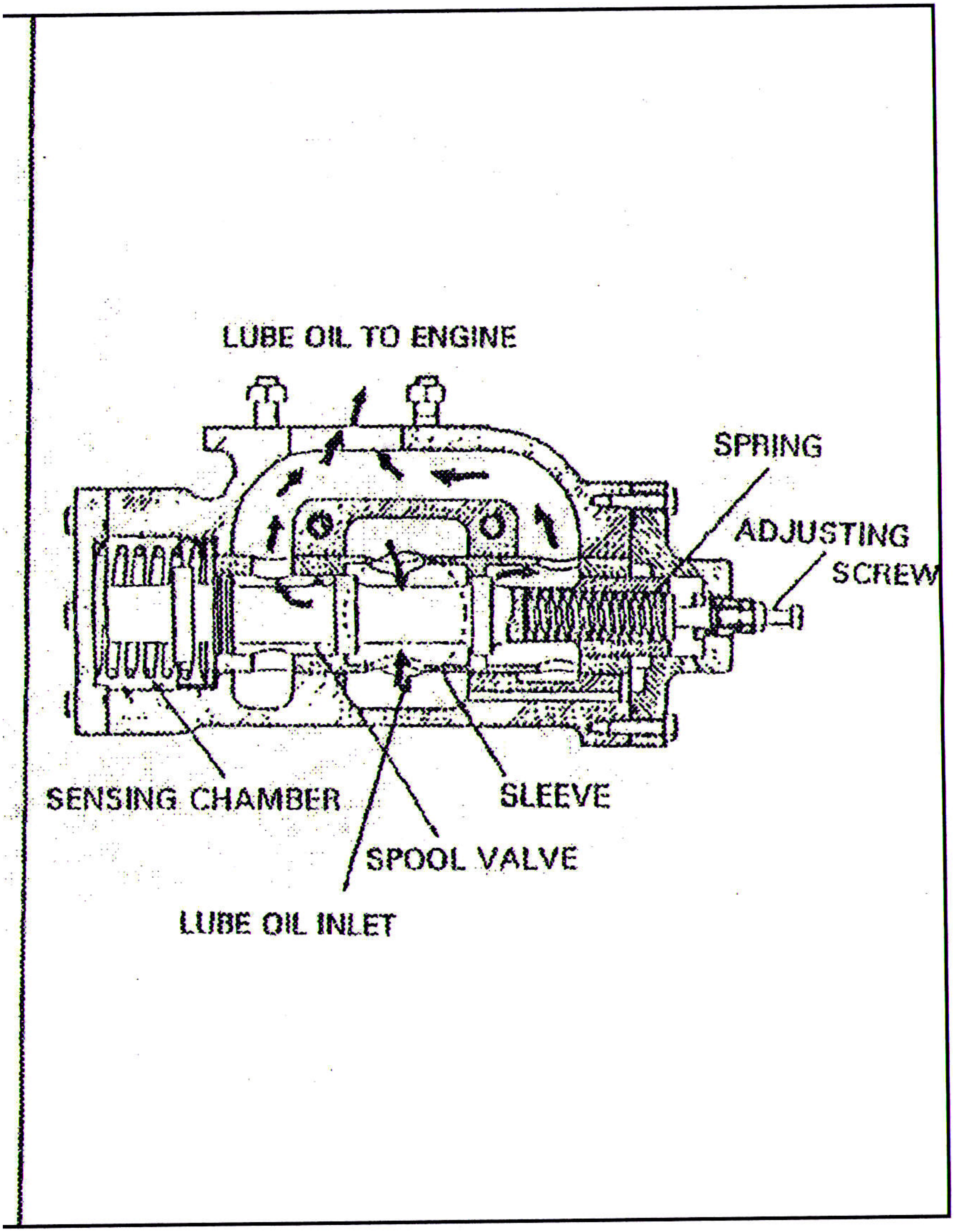

Figure 5-12 Pressure Regulating Valve

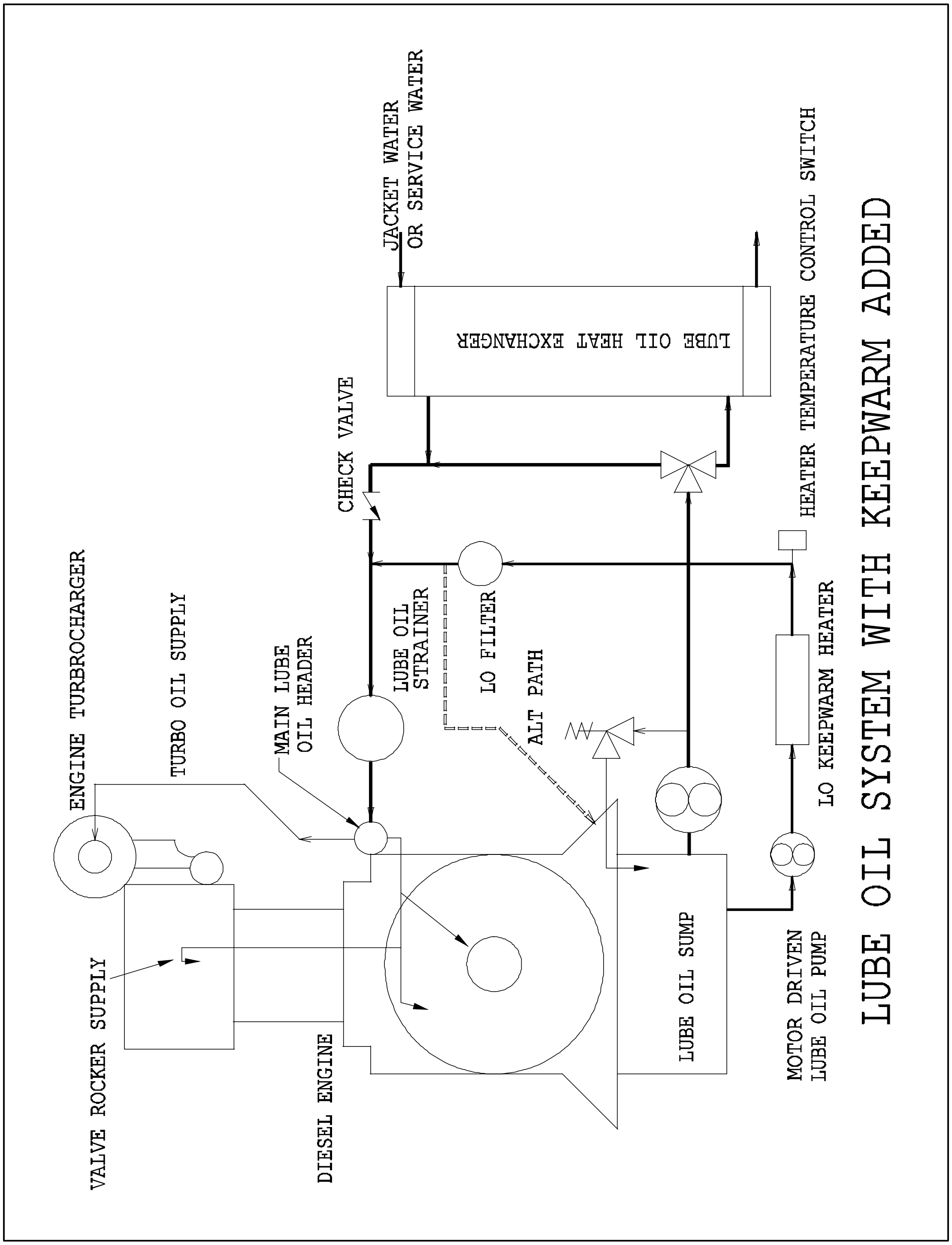

Figure 5-13 Lube Oil System with Keepwarm Added

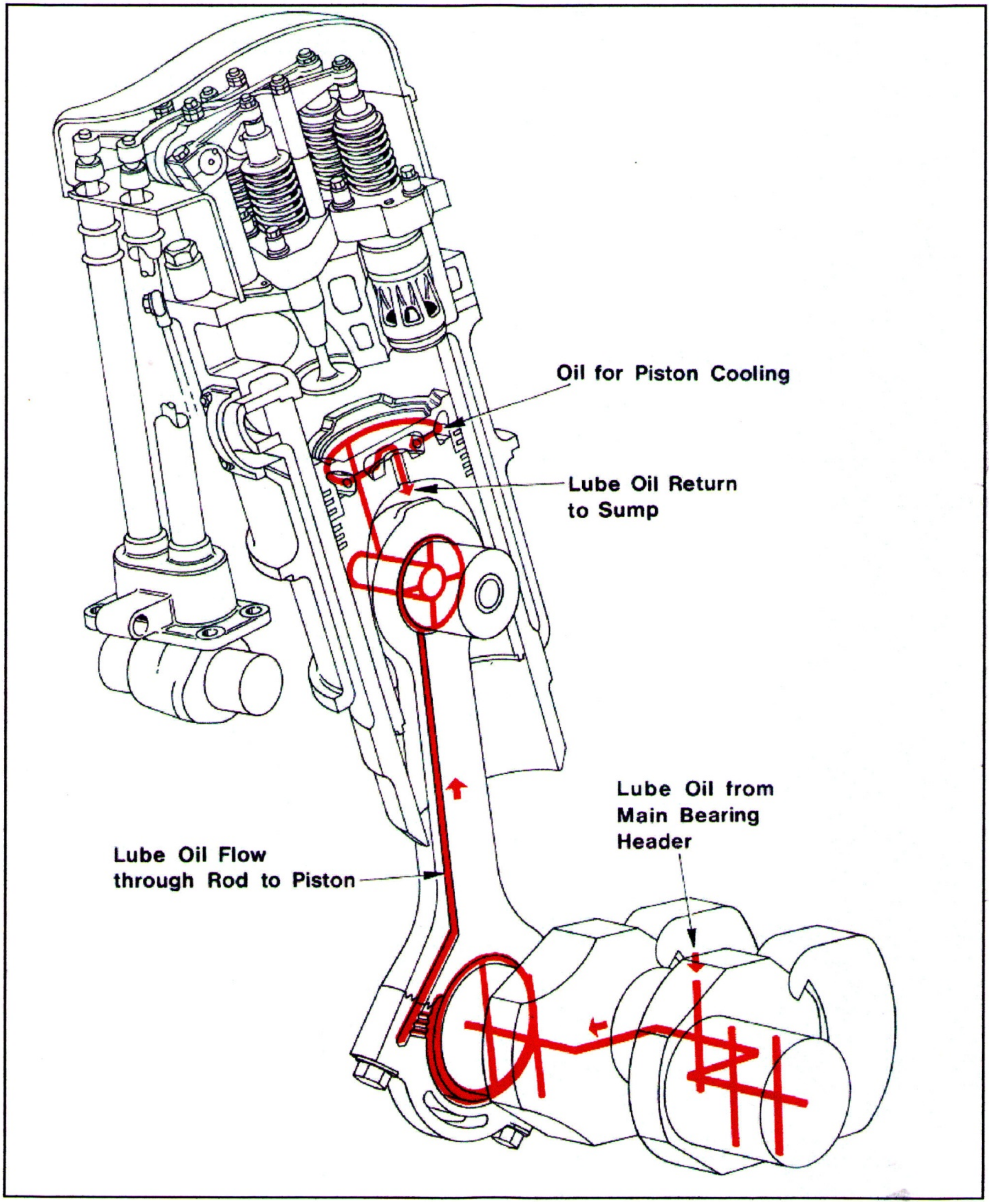

Figure 5-14 Pielstick Lube Oil Flow

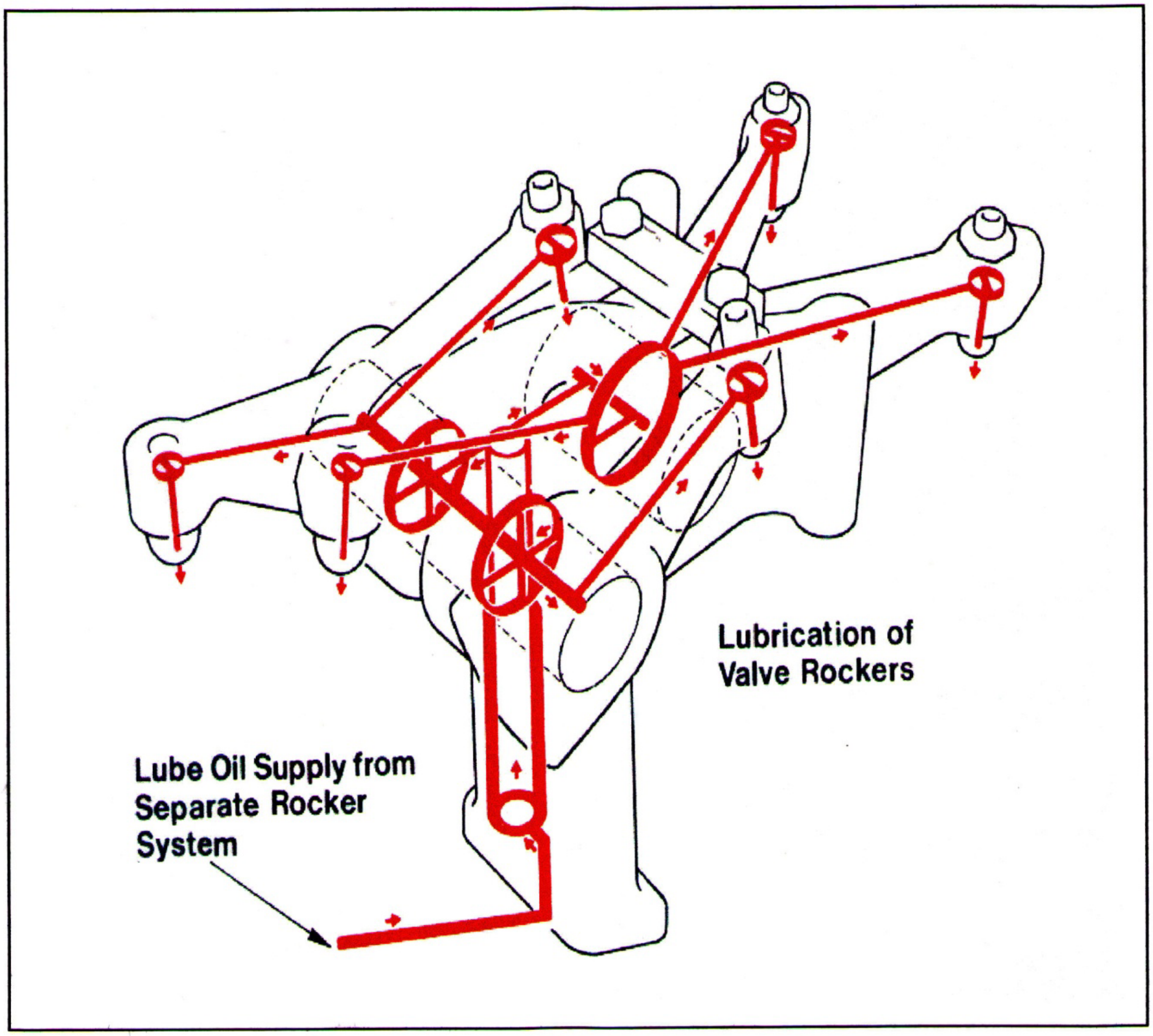

Figure 5-15 Pielstick Valve Rocker Flow

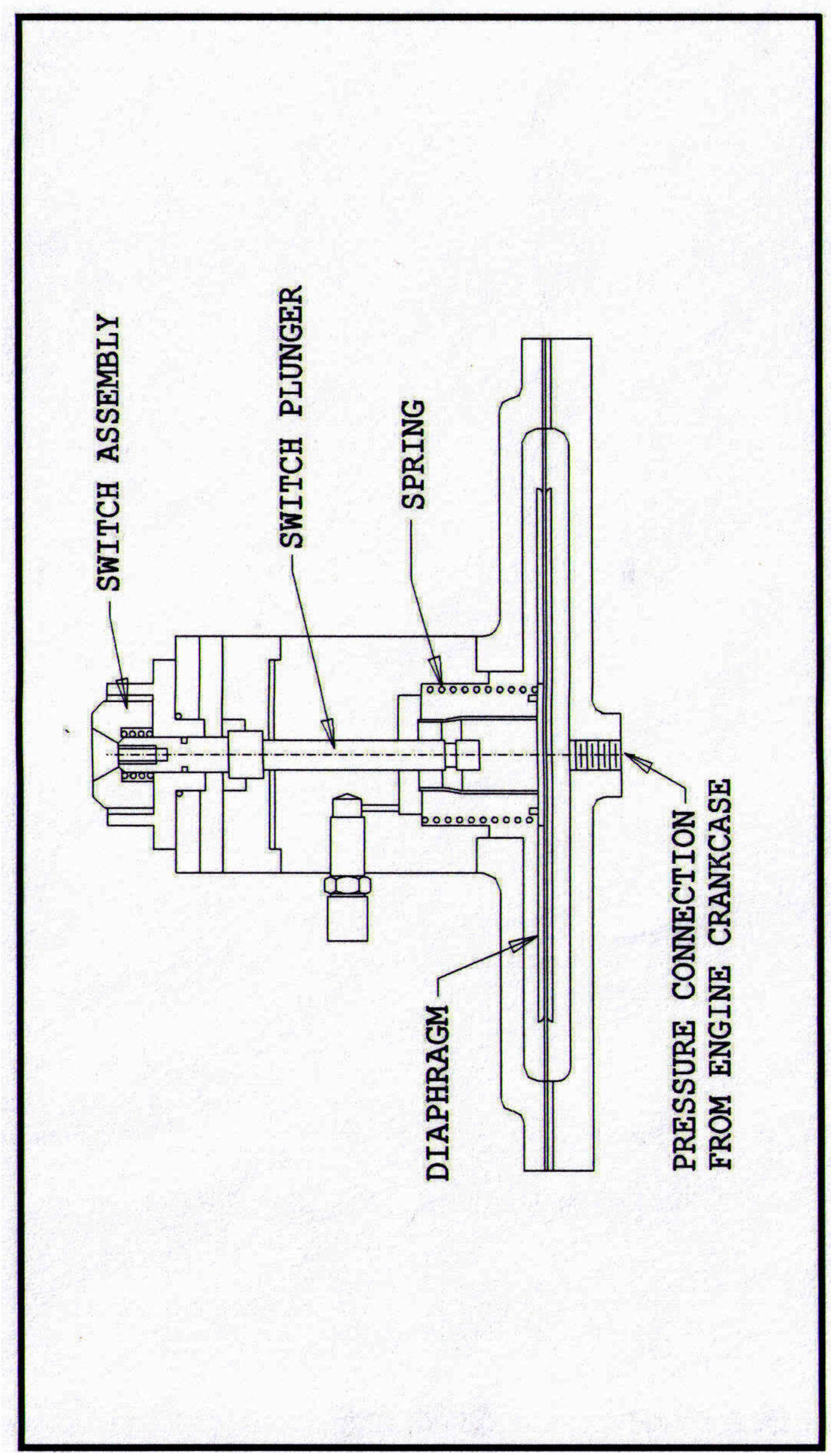

Figure 5-16 Crankcase Diaphragm Type Pressure Monitoring Switch

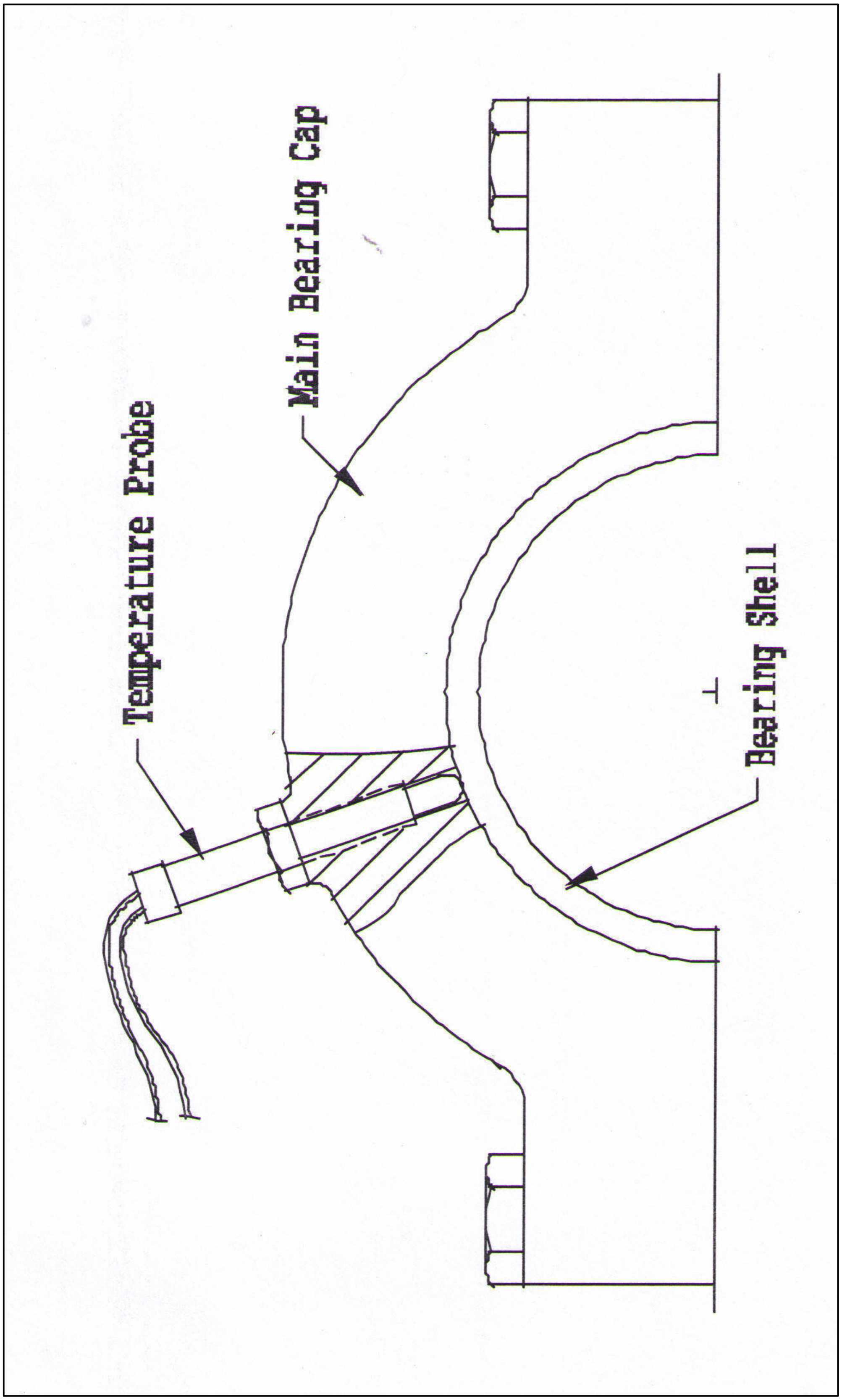

Figure 5-17 Bearing Temperature Probe

HANDS-ON SESSION 7

7.0 ENGINE LUBRICATION SYSTEM

Purpose

The purpose of this session is to complement classroom instruction of Chapter 5.

Learning Objectives

Upon completion of this lesson you will:

- Be familiar with the appearance, location, function, and operation of the lube oil system and its components.

7.1 Lube Oil Flow Path

The instructor will use the rotatable cutaway OP to show the oil flow paths:

- From the engine's lube oil sump through the engine-driven oil pump to the thermostatic valve then either through the lube oil cooler or directly to the duplex oil strainer/filter
- Into the main lube oil header(s)
- From the header(s) to and from the turbochager back to the engine
- From the header to the main bearing caps then through drilled passages to the crankshaft journals and connecting rod bearings
- Through the connecting rod drilled passages to piston wrist pin bearings through holes into the piston cocktail shaker with its drain back to the sump

The instructor will discuss the pre-lube keepwarm oil system and its components. The presentation will include the fact that the engine cylinder can become hydraulically locked so that the engine would not start and engine damage might occur. The cylinder test cocks need to be opened to roll the engine over prior to all planned starts to purge cylinders of lube oil and water. Licensee's procedures need to insure the opening and closing of these cocks for standby operation.

The instructor will discuss the problem of lube oil accumulation in exhaust manifolds with seepage and lube oil fires outside the exhaust manifold near the governor. Also fires inside the exhaust manifold with the possibility of turbocharger damage from the blowtorch effect.

The instructor will show differences in the 4-stroke cycle engine lube oil flow paths which include lubrication of the cylinder head valve rocker arm assemblies.

Based upon typical oil consumption rates for the OP and ALCO engines, he will tell students how much lube oil the engines will consume at rated load each day/week, how and when lube oil sump level should be checked, and how to add lube oil to a running engine sump. He will point out the crankcase exhauster location and discuss its source of power and its exhaust flow.

The instructor will show the location, function, and operation of the crankcase sump pressure relief blowout covers and how the covers are checked for proper operation.

7.2 Components

The instructor will show cutaways and

discuss the functioning of the following components:

- Gear-driven lube oil pump
- Thermostatic valve
- Pressure relief valve
- Duplex filters/strainers
- Main bearing cap showing drilled oil passages
- Crankshaft showing drilled oil passages
- Connecting rod drilled oil passages
- Piston showing drilled oil passages to the cocktail shaker and its drain back to the lube oil sump
- Oil cooler
- Brown Boveri turbocharger with its separate oil sump
- Elliot turbocharger with its engine-supplied lube oil
- Piston with oil control rings